

Stars with Unusual Compositions: Carbon and Oxygen in Cool White Dwarf Stars

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1. INTRODUCTION

White dwarfs represent the end products of the evolution of all stars on the main sequence that had initial masses below $\sim 8M_{\odot}$. After some important mass-loss episodes in the red giant phases, followed by the end of thermonuclear activity in the interiors of such stars, they ultimately shrink to Earth-size objects with masses of about 0.4 to 1.2 M_{\odot} . The vast majority of them are believed to be composed mainly (i.e, more than 99% by mass) of carbon and oxygen, the products of hydrogen and helium nuclear burning. Intuitively, then, one might assume that it would not be surprising to observe a significant amount of carbon and oxygen in white dwarf photospheres. However, nuclear burning and mass loss episodes do not consume 100% of the hydrogen and helium initially present in each star at birth. With a surface gravity of the order of $\log g \sim 8$, gravitational settling in white dwarf stars is quite efficient and the light elements leftover from previous evolutionary phases rapidly float to the surface, while heavier elements sink out of sight. Since there is ultimately more than enough hydrogen and helium to form an optically thick photosphere, it is not possible to directly observe the white dwarf core material. Thus, the majority of white dwarfs are thus found to have a surface composition that is completely pure in hydrogen or helium².

Nevertheless, carbon and oxygen features are still found in the spectra of several hydrogen-deficient objects, namely, the PG 1159 stars, the DQ, DBQ and Hot DQ white dwarfs. In the case of the hot PG 1159 stars ($T_{\text{eff}} \sim 75,000$ K and up), the presence of these elements is somewhat easier to understand since the gravitational separation of the elements is simply not completed yet. A thorough review of the observed properties of the extremely hot, hydrogen-deficient post-asymptotic giant branch (post-AGB) stars has already been written by Werner and Herwig (2006), and they are not discussed further here.

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²Recent studies have revealed that many cool white dwarfs also have CaII H & K lines when observed at sufficiently high resolution (see Zuckerman et al., 2010, and references therein). The presence of heavy elements in these objects is now believed to be the result of the accretion of nearby planetesimals or asteroids. Since these objects represent a class of their own, and are detailed elsewhere in this volume, this chapter contains no further discussion of the impure atmospheres found in as DAZ, DZ, and DBZ white dwarfs.

In cooler stars, for which the process of radiative levitation can be considered negligible and gravitational settling has had sufficient time to transform PG 1159 stars into helium-dominated objects, other physical mechanisms must be called upon to explain the presence of observable amounts of carbon (and sometimes oxygen). The following chapter is a broad review of the observational signatures, physical properties, and evolution of DQ, DBQ and Hot DQ white dwarfs, and also present an overview of the main challenges that future investigations of these types of object should try to address. Although these spectral types together represent only a small fraction of the total number of white dwarfs, they nevertheless provide extremely valuable information about the evolution of stars following the AGB phase as well as the spectral evolution of white dwarfs in general.

[The 45 page chapter, complete with figures, tables, and references can be found in its entirety in "White Dwarf Atmospheres and Circumstellar Environments", ed. D. W. Hoard, Wiley-VCH, ISBN 978-3-527-41036-6, published in September 2011.]